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EMBODIED ENERGY ANALYSIS OF RAMMED EARTH CONSTRUCTION FOR AN ENVIRONMENTAL EDUCATION BUILDING IN POZUELO DE ALARCÓN (MADRID, SPAIN)

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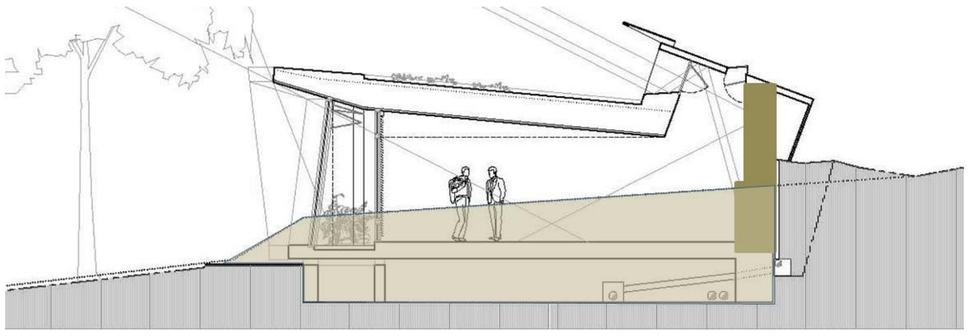
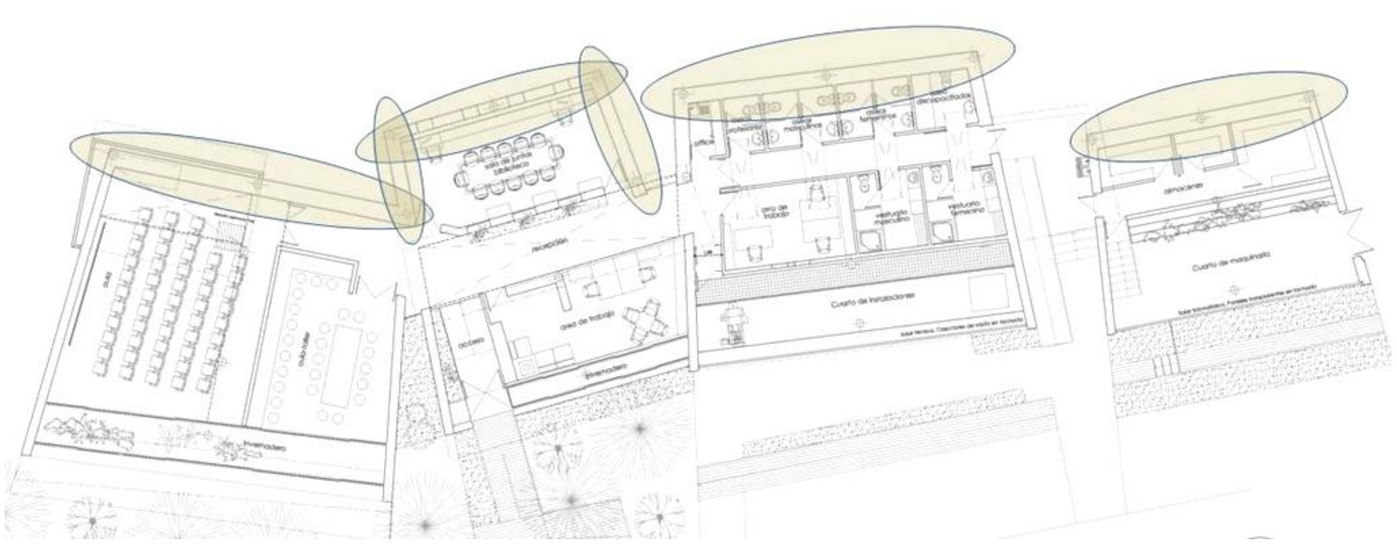
Front view of the classroom. South façade. Location of earth walls.

The initial proposals intended that the building would answer the most representative words of its title, namely: "Classroom", "Education" and "Environment". For the first and second, the configuration of the building itself should teach. For the third, must bring together all aspects that are part of the basic concepts of sustainable construction, employing passive environmental conditioning strategies based on their design, using low impact materials, and making effective management of resources such as water and energy.



Section through the events hall. Representative sec-tion of the building, showing soil interaction.

Architects: Antonio Baño Nieva, Francisco Javier Castilla Pascual, Alberto Vigil-Escalera.



The use of excavation material itself, reduces very significantly the environmental costs resulting from the act of building. On the one hand earth does not pollute or consume energy in transport, and also helps to reduce landfills. Furthermore, we are using a material that does not require manufacturing or transportation

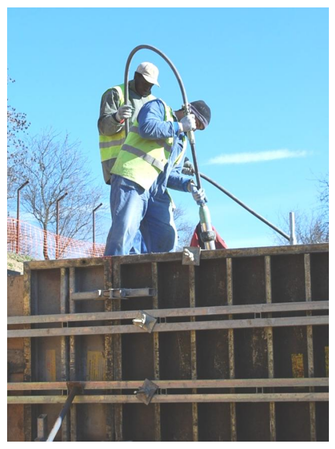
As expected, the volume of soil to excavate was very considerable, so we had to enable and adjacent area to store the vast amounts of soil.A Standard Proctor test UNE 103500:1994, was made ,like the rest of tests corresponding to this phase of work, in the laboratories of the European University of Madrid. The test we determined that the optimal values of humidity are at 11.4% for a dry density of 1.7 g/cm3, these amounts will set the standard on which the following activities will revolve. Both, grain size characterization of the soil as the tests made for compressed earth block production, suggested the need of additives compensating for the absence of clays in the soil. After the completion of several samples, the final mix proportions include 4% lime (calcium hydroxide CL S-90) and 4% cement (CEMII / B-LL 32.5N) by weight.

So it is advisable, in both cases (internal and external surfaces), a reinforcement of the surface conditions of the wall. One purpose of the use of soil as building material in the “classroom”, was to establish a link, firm and deep, between the ancient ways of doing and the real possibilities of their current application. Technical forgotten works can be resuscitated and treated, to be used with renewed meaning. It was therefore proposed a traditional “*calicostrado*” could contribute effectively to achieve the performance required.

The formwork system with metal panels, stretched and top and bottom stud fastening that allow free soil compaction, secured with braces and anchored to the ground with wedges, becomes, within the current market proposals, as the best option. Surely not represent the most appropriate (for example, difficulting the elimination of excess water during drying), but aids to lower costs and to use common tools bringing earth construction to a conventional choice.

The mixing of soil, with the proportions of additives already referred to, and subsequent mixing, is made by mini dumper machine (bobcat), that allow both the displacement of the earth from its place of storage to the point of preparation, and perform works of incorporating additives, even leaving a finest mixing to workers.

Manual compaction does not require special attention (for accumulation of experience) in terms of technique is concerned. Finally, we chose the compactor Sullair F18, weight of 17.5 kg and a height of 126 cm, very manageable, able to work with a frequency of 500 beats per minute and with a 14.5 cm diameter ram, very suitable for the small scale on which we work.



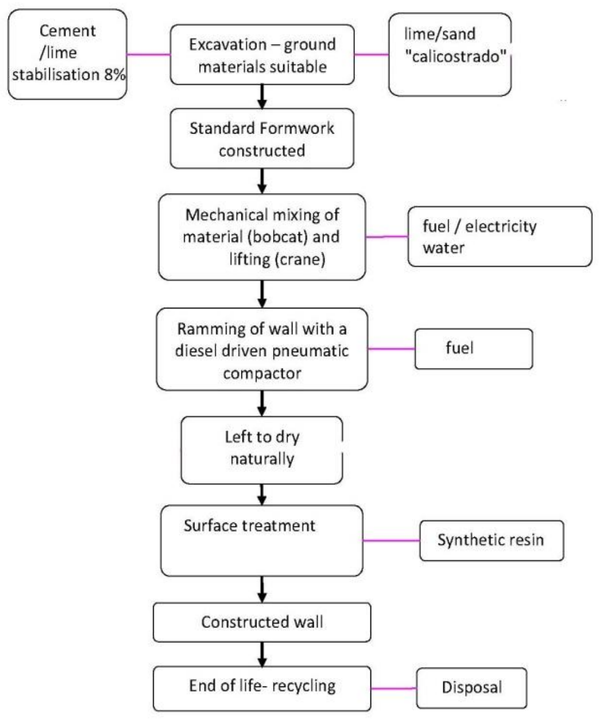


Diagram adapted form Lax (2009).

To study the environmental profile of our wall we will follow the process diagram proposed by Lax (2009), for a generic rammed earth wall LCA, attending to those particular conditions of our building. Due to the difficulties to obtain real energy consumption data from the jobsite, an estimation has been made from the environmental values extracted out the BEDEC database.The final embodied energy obtained (2755 MJ/m3) approaches the one from a brick masonry wall (29 cm thick) with 2970 MJ/m3 and it is over 1134MJ/m3 for a stone masonry wall and far from 7354MJ/m3 of a reinforced concrete wall.

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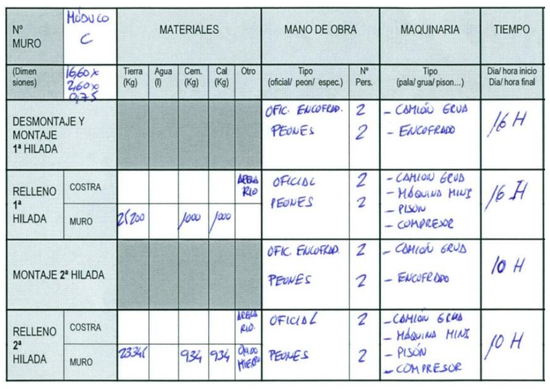

Nº MURO	Módulo C	MATERIALES					MANO DE OBRA		MAQUINARIA	TIEMPO
(Dimensiones)	1660 x 2605 x 775	Tierra (Kg)	Agua (l)	Cem. (Kg)	Cal (Kg)	Otro	Tipo (oficial/ peon/ espec.)	Nº Pers.	Tipo (pala/ grua/ pison…)	Dia/ hora inicio Dia/ hora final
DESMONTAJE Y MONTAJE 1ª HILADA							OFIC. ENCOFRAD.	2	- CAMIÓN GRUA	
							PEONES	2	- ENCOFRADO	16 H
RELLENO 1ª HILADA	COSTRA					ARENA RIO	OFICIAL	2	- CAMIÓN GRUA - MÁQUINA MIXT - PISÓN - COMPRESOR	
	MURO	2(300		100	100		PEONES	2		16 H
MONTAJE 2ª HILADA							OFIC. ENCOFRAD	2	- CAMIÓN GRUA	
							PEONES	2	- ENCOFRADO	10 H
RELLENO 2ª HILADA	COSTRA					ARENA RIO	OFICIAL	2	- CAMIÓN GRUA - MÁQUINA MIXT - PISÓN - COMPRESOR	
	MURO	2336		934	934	CAL MACH	PEONES	2		10 H

Data report from wall construction.

Embodied energy in stabilized earth wall (4% ce-ment + 4% lime, by weight) mechanically compacted with an average density of 1900Kg/m3, formwork with phenolic mod-ular panels, mechanical mixing and pouring with concrete bucket from crane truck (3 m heigth), lime-crusted one side, compacted by mechanical means. With thickness between 75-60 cm.

Consumption	units	Energy Cost	
	Kg/m2/h	MJ	kwh
material components	Kg	Cost per unit	1.640,85	455,79
water	50	0,006	0,3	0,08
sand	284,15	0,15	42,6225	11,84
cement	75,1	3,77	283,127	78,65
lime	162,34	4,82	782,4788	217,36
earth	1665,7	0,18	299,826	83,29
watproof	2,5	93	232,5	64,58
Additional components	m2		1.018,97	283,05
formwork	2,66	383,07	1018,9662	283,05
machinery	h-		95,2672	26,46
Gas.compresor	0,5	60,86	30,43	8,45
Mixing (bobcat)	0,12	304,31	36,5172	10,14
crane	0,24	118	28,32	7,87
Total			2.755,09	765,30

As it has been demonstrated an exhaustive definition of the materials and techniques used during a rammed earth construction is necessary to asses rightly the embodied energy of the whole process. Energy consumption varies greatly depending on the tools and materials used, so it results much more important to establish the components of the generic construction process to permit changes depending on each specific project requirements and characteristics. The values obtained and the method followed supposes an advance that will allow using this data as a reference in environmental assessment tools for buildings like VERDE-Sbtool. Further research must be done to characterize other indicators as CO2 emissions, and waste disposal.